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Photovoltaic System under Uneven Light Condition and Variable Load with Modified Incremental Resistance Algorithm

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Key words: Local MPPTs, Global MPPTs, MPPTs, Uneven Lighting Conditions (ULCs), Incremental Resistance (INR)

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Abstract: On scrutinizing P vs. V curves of P_V arrays which receives non_uniform insolation of light or simply during Uneven_Lighting_Conditions (ULCs) multiple LMPPTs are exhibited. Conventional MPPT methods are efficient in normal conditions even though they failed to identify the GMPPTs from LMPPTs under ULCs. To improve productivity of Maximum_PPT method for P_V arrays under both ULCs and normal conditions some modifications are tried in this study. The Incremental_resistance_method added with some alterations enables to track the LMPPTs as well as GMPPTs very effectively and accurately with less numbers of steps. In proposed system, losses during GMPP tracking is minimized under ULCs. Simulation is performed in MAT_LAB.

INTRODUCTION

Surmount the paucity of energy, Sun is the effective option. But the incipient expenditure and the vast land requirement made the choice impediment. So, an infinitesimal loses in power results unprofitable. If wisely used this energy could overcome energy demands and moreover it is clean and easily available.

Global-MPPT of P_V array in all conditions guarantee the extreme power possibly obtained from sun. Popular MPPT methods like ripple correlation technique, Short_Circuit_Current (SCC) technique and Incremental_Conductance (IC) methods are effective during normal light insolation condition but these methods seems to be struggled to find GMPPTs under ULCs conditions, i.e., when modules of solar array didn't receives uniform insolation of light. During normal solar insolation conditions P vs. V curves of PV arrays exhibit only one peak, Multiple LMPPTs may be viewed in P vs. V curves of P_V arrays under ULCs. Hence, several MPPT methods are proposed, especially, applicable for solar arrays under ULCs which can be listed into two groups: hardware_based and software_based methods.

By Hsieh *et al*.[1] INC-algorithm is modified to solve a simple first degree polynomial equation to locate Global-MPP but hardware Complexity is being increased as it require more measuring components and circuits also it couldn't assure to locate Global-MMP in P Vs V curves which is having more number of peaks.

By Femia *et al*.[2] P&O algorithm, is modified by adjusting he duty cycle between maximum and minimum value of dc/dc_converter and almost all the LMPPs are identified but consumption of time is more. By Kollimalla and Mishra[3]. Fuzzy_logic based HC algorithm stores all the inter maximum values repeats in MCU and from saved data Global-MPPT is obtained using fuzzy. Although, the system become precise one but complexity of system and time consumption increased, consequently it get less importance.

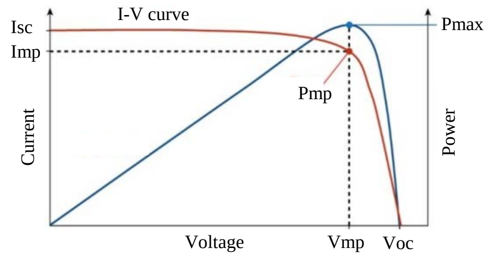

Fig. 1: P_V and IV characteristics of P_V module under normal light condition

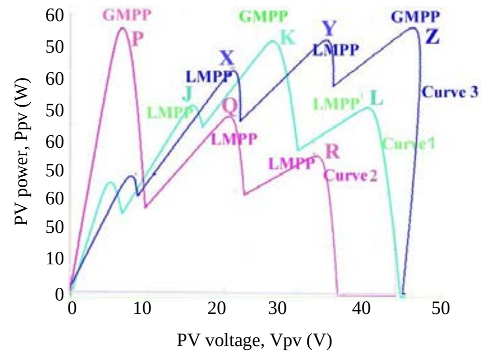

Fig. 2: Pow-Volt curves of the P_V array under ULCs

By Liu *et al*.[4] particle_swarm_optimization GMPPT is located precisely using a velocity equation, even though error in setting governing equation parameters may cause entire system disrupt. Figure 1 shows the Pow-Volt and I(current)-Volt characteristics of P_V module during normal light condition.

An extensive research on P_V curves under ULCs reported by Ramyar *et al*.[5] reveals the hike in the curve occurs approx at the 0 8*Voc and curve exhibit the tendency to rise before GMPP and fall afterwards considering above characteristics PO- algorithm is mostly utilized to identify the LMPPs and Global-MPP[5]. Even though under ULCs the accuracy of P_O algorithm is doubtful.

Here, a method which finds GMMP under ULCs very accurately along with good performance in above mentioned factors is tried. This system perform by mapping solar insolation pattern using the P_V current measured at defined points and choose appropriate points for LMPPT, then it performs INR in these points and all the LMPs are obtained by LMPs comparison GMP is identified.

MATERIALS AND METHODS

Proposed algorithm: In this, a few conclusion under ULCs reported by Ramyar *et al*.[5] are employed. The conclusion referred are the hike in curve occur approx. at the 0.8Voc and curve exhibit the tendency to rise before GMPP and fall afterwards. Here, Incremental_resistance is realized instead of P_O because of its consistency under ULCs. A new algorithm is introduced to track the MPPs instantly. From above conclusion, the GMPP may be located in the middle of three successive hikes or it may be situated at either ends of the Power-Volt curve. Consequently, there exist 3 types of hike in Pow-Volt_curve (Fig. 2).

The 1st one is where the Global-MPP lies in mid of the others LMPPs as in Fig. 2. The other 2 probability are the location of the Global-MPP at the either side of the Pow-Volt_curve and the value falls when hikes are far away from the Global-MPP, refer curve 2 and 3 in Fig. 2. In all these Local-MPPs, the proposed set of rules NDS three successive hikes and identify the highest value. If Global-MPP is not available in the mid of the 3 hikes, the algorithm advances to exploit until the Global-MPP is in the mid or until the end of the Pow-Volt curve where the min or max achievable voltage is showed up. Following sections dealt with the set of rules used to record the Global-MPP in 3 distinct types of multiple hikes Pow-Volt curve. The two variables taken are the Voc of the P_V module and the max number of series-connected module (Mmax).

Case_I; Global-MPP lies in the middle of other two local-MPPs: Refer to flowchart, Fig. 3 initially, the values of power Pmpp_1, Pmpp_2, Pmpp_3 and duty_cycles Duty_1 Duty_2 Duty_3 are adjusted to zero value (block_1). Then Mmax and the Voc are adjusted (block_2). Afterwards the conventional INR method (block_3) is utilized to get maximum_power at point_J (curve1) see Fig. 2, then converter's duty_cycle is saved into Duty_1 and the power is saved into Pmpp_1 (block_ 4). Afterwards check whether Vmax (Voc multiplied with Mmax) is attained or not (block_5), if not attained the algorithm will search right side of point_J to get new MPP (curve 1). As in [13] at MPPs the value of voltages vary with 0 8*Voc from each other therefore Vref is incremented by 0 8* Voc to Vmpp_1 (block_6).

Then to ensure convergence of point of operation of the P_V array very close to point_K a subroutine MPP tracker (block_7) is used in Fig. 3 before the INR method (block_8) is utilized to identify the maximum_power at point_K. Consequently at point_Kconverter's duty_cycle is stored as Duty_2 and power is stored as Pmpp_2 (block _9). If Pmpp_2 value at point_K is higher than the value of Pmpp_1 (block_10) see Fig. 3 the algorithm moves to block_ 11 and Pmpp_1 and Duty_1 at point_J is replaced with Pmpp_3 and Duty_3. Then, Pmpp_2 and Duty_2 point_K are saved into Pmpp_1 and Duty_1. In brief Pmpp_1 always contains highest value of MPP. Then it goes back to block_5 and continues the search to identify Pmpp_2 at right side of Pmpp_1 from block 6 to block_ 9 until the Vmax is reached.

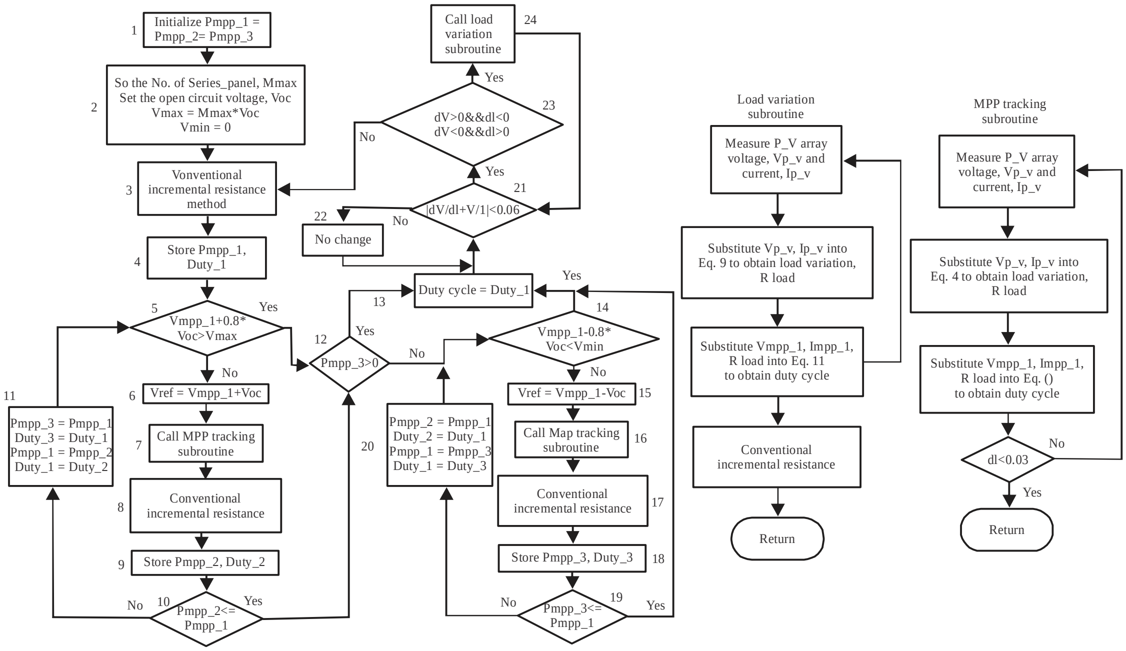

Fig. 3: Flowchart of proposed system

Algorithm reach block_12 when the value of Pmpp_2 at point_L is below Pmpp_1 at point_K .Since Pmpp_3 has data of point_J, Duty_1 will be used as the dc/dc_converter's on-off period (block_13) after that returns to block_21. To ensure P_V system is still at GMPP equation_1 is utilized:

$$\frac{dV}{dI}+\frac{V}{I}\leq 0.06 \tag{1}$$

Generally, Eq. 1 is equates to zero but in real situation it is not possible to get zero because of truncation_error, hence, 0.06 error is permitted to terminate the fluctuations while operating under steady-state and thereby, increasing the P_V system efficiency. Then, it goes from block_21 to block_ 22 and then back to block_21 as long as there is no ULCs.

Afterwards, the algorithm moves to block_23 and changes in voltage as well as current is identified. The transition in current as well as voltage of the P_V array during ULCs is referred in Table 1. When load resistance changes the voltage variation will be different from current variation. Hence, subroutine load variation is called to ensure tracking of GMPP very quickly. If there occurs a change in solar insolation rate the changes occurs in current and voltage are similar. Then the proposed algorithm restarts from block_3 to track maximum current and voltage of P_V array.

Case_II; GMPP located left side or right side of all the MPPs: As same as first case variables such as Voc, Mmax are set (blocks_1 and block_2). Then, the

Table 1: Voltage and current variation under ULCs

Parameters	Variation in current (dI)	Variation in voltage (dV)
Solar insolation		
Increases	Increases	Increases
Decreases	Decreases	Decreases
Load resistance		
Increases	Decreases	Increases
Decrease	Increases	Decreases

Increment_resistance (block_3) is utilized to obtain the Maximum_power at point_Q in curve 2 similarly it finds Point_X in curve 3 and the P_V array's power and on-off period of the dc/dc_converter are stored into Pmpp_1 and Duty_1 (block_4). Afterwards, it check whether Vmax (Voc multiplied with Mmax) is attained or not (block_5), if not attained the proposed_algorithm will search right side of point_Q to get new MPP (block_6 to block_9) in case of curve 2, similarly proposed_algorithm will search right side of point_X to get new MPP (block_6 to block_9) in case of curve 3. Then in curve 2 the proposed_algorithm compares Pmpp_2 point_R to Pmpp_1 point_Q (block_10) and in case of curve 3 it compares Pmpp_2 point_X to Pmpp_1 point_Y (block_10). Since, Pmpp_2 lower than Pmpp_1 the algorithm jump to block_12 in case of curve 2 and jumps to block_11 in case of curve 3. If Pmpp_3 value is not registered yet block_13 and the Vmin is not equal to zero (block_14) the algorithm continues to identify Pmpp_3 point_P the left hand side of Pmpp_1 in case of curve 2 and algorithm continues to identify Pmpp_3 point_Z the right hand side of Pmpp_1 in case of curve 3. The Vref is decreased by 0 8*Voc (block_15) in case of curve 2 and increased by 0.8*Voc in case of curve 3. A subroutine MPP tracker (block_16) is call up on to obtain the point of operation of the P_V array nearer to the maximum_power at point_P before the INR (block_17) is utilized to identify the Pmax at point _P. The value of point_P are saved into Pmpp_3 and Duty_3 (block_18). Since, Pmpp_3 point_P is more compared to Pmpp_1 point_Q, the data of point_Q are now saved to Pmpp_2 and Duty_2 and the values of point_P are now saved into Pmpp_1 and Duty_1 (block_20). Then, the algorithm return to (block_14) and Duty_1 is used as the converter's duty_cycle since Vmin is achieved. In the case of curve 2, the P_V system operates at the leftmost side of the P_V curve (point_P) which is its Global-MPP, similarly, the P_V system operates at the rightmost side of the P_V curve (point_Z) which is the Global-MPP in case of curve 3. Finally, the algorithm starts looping between block_21 to 22, till it observe any variation in ULCs.

Conventional increment resistance method: Power (P) when differentiated w.r.t Current I and equate to zero variables of INR algorithm is obtained. Consequently, the slope of the P_V array will be zero at maximum_power Point, also negative or positive on either side of maximum_power point, given by:

$$\frac{dP_{P\_V}}{dI_{P\_V}} = 0,\ \text{MPP}$$
$$\frac{dP_{P\_V}}{dI_{P\_V}} > 0,\ \text{MPP left} \quad (2)$$

$$\frac{dP_{P\_V}}{dI_{P\_V}} < 0,\ \text{MPP right}$$

Since:

$$\frac{dP_{P\_v}}{dI_{P\_v}} = \frac{d\left(I_{p\_v}V_{p\_v}\right)}{dI_{p\_v}} = V_{p\_v} + I_{p\_v}\frac{dV_{p\_v}}{dI_{p\_v}} \cong V_{p\_v} + I_{p\_v}\frac{\Delta V_{p\_v}}{\Delta I_{p\_v}} \quad (3)$$

Equation 3 becomes

$$\frac{\Delta V_{p\_v}}{\Delta I_{p\_v}} = -\frac{VV_{p\_v}}{I_{p\_v}},\ \text{MPP}$$
$$\frac{\Delta V_{p\_v}}{\Delta I_{p\_v}} > -\frac{V_{p\_v}}{I_{p\_v}},\ \text{MPP left}$$
$$\frac{\Delta V_{p\_v}}{\Delta I_{p\_v}} < -\frac{V_{p\_v}}{I_{p\_v}},\ \text{MPP right}$$

The maximum_power point can thus be identified by matching the values of Vp_v/Ip_v with the ΔVp_v/ΔIp_v. Iref is the reference_current at which the P_V array is pushed to operate. At the maximum_power point, Iref becomes IMPP. Once the maximum-power point is achieved, the point of operation of P_V array is maintained at that level until a variation in voltage is noted indicating ULCs. The value of Iref is decreased or increased to identify the new maximum_power point. The P_V array Pout is applied to directly control the dc/dc_converter output Iref which is also the output Iref of the P_V array, contributing to a noncomplex control-system.

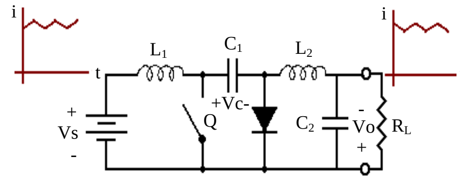

Fig. 4: Dc/Dc_CUK converter circuit

Calculate duty cycle for CUK converter: A dc/dc-converter is connected between P_V and load. Equation 5 and 6 show the relationships between the output-voltages and input_current of the dc/dc_converter (CUK). Figure 4 shows CUK converter circuit:

$$V_{in} = \frac{1\text{-}D}{D} V_{out} \quad (5)$$

$$I_{in} = \frac{D}{1\text{-}D} I_{out} \quad (6)$$

Divide Eq. 5 by Eq. 6 to get Eq. 7:

$$Z_{in} = \frac{(1\text{-}D)^2}{D^2} Z_{out} \quad (7)$$

Where:
D→converter's Duty_cycle
V_{in}→converter's input voltage
I_{in}→converter's input current
Z_{in}→converter's input impedance
Z_{out}→converter's output impedance
Z_{load}→Load impedance

In the PV system (Eq. 7) can be rewritten to obtain Eq. 8 and 9:

$$\frac{V_{p\_v}}{I_{p\_v}} = \frac{(1-D)^2}{D^2} Z_{load} \quad (8)$$

$$Z_{load} = \frac{D^2}{(1\text{-}D)^2}\frac{V_{p\_v}}{I_{p\_v}} \quad (9)$$

At any operating point (Vp_v, Ip_v) of the P_V array and the D is known, the Z_{load} at the converter output can

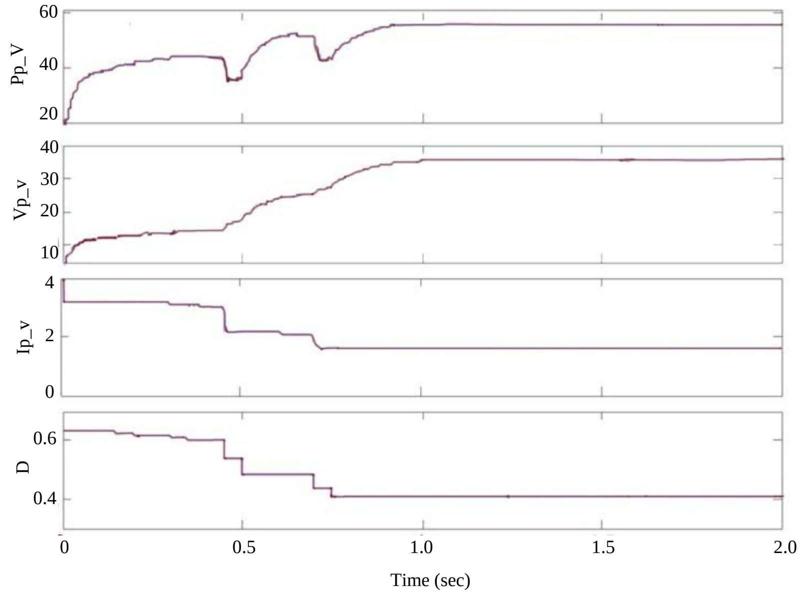

Fig. 5: Results of simulation for the P_V system under uneven lighting conditions where the solar insolation values for each of the 18-series_connected P_V cells are (a) 1.2, 0.8, 0.6 and 0.5 kW^{-2}

be obtained by using Eq. 9. After getting the value of load impedance, Eq. 9 becomes Eq. 10. With known voltage and current of the P_Varray, using Eq. 11 the on-off period (Duty_cycle) can be calculated. This Duty_cycle is utilized by converter to required voltage and current:

$$\frac{D^2}{(1\text{-}D)^2}=\frac{I_{p\_v}}{V_{p\_v}}Z_{load} \tag{10}$$

$$D=\frac{\sqrt{\frac{I_{p\_v}}{V_{p\_v}}Z_{load}}}{1+\sqrt{\frac{I_{p\_v}}{V_{p\_v}}Z_{load}}} \tag{11}$$

RESULTS AND DISCUSSION

The model of P_Varray under ULCs,the CUK_converter and Maximum-PPT controlled are generated in a MAT_LAB Simulink model. These pecification of the P_V module in the P_Varray refer Table 2.

The converters component values are: C_{in} and C_{out} = 3900 µF, L1 and L2 = 125 µH and 10-Ω resistance as load. The switching frequency for the switch (Insulated-gate-bipolar-transistor) is adjusted to 25 kHz. In this, maximum_power point tracker controller sampling time is adjusted to 0.05s and the converter's duty_cycle step size is set to 0.005. Model have one by_passdiode across eighteen-series connected P_Vcells

Table 2: Specification of P_V Module (KC85T) under 25°C and 1000 W insolation

Quantity	Values	Units
Maximum power	86.95	W
MPP voltage	17.44	V
MPP current	5.02	A
Voc	21.7.0	V
Isc	5.34	A
No. of series cells	36 .00	
No. of series cells with Bypass diodes	18.00	

in the module which means 2 by_passdiodes in one P_V module. Therefore, there are maximum chances of producing 2 maximum-power points by one P_V module during ULCs. Therefore, here, Voc is taken as 10.8V which is half times the Voc of the P_V module. Then, parallel connected by_passdiode P_V module create the P_V array. Hence, two-series connected P_V modules have maximum of 4 hikes during ULCs. Figure 5 shows the simulation results for two different ULCs where 4 distinct level of solar in solation on each of th eeighteen-series_connected P_V cells in the two-series_connected P_V modules. Initially, using conventional INR method first MPP, (P1) is identified (which is stored into Pmpp_1) and then the algorithm goes to the right of P1 (uses MPP tracking subroutine algorithms in block_7 for fast computation of duty_cycle) to find the next MPP (P2). Since, P2 (51.4 W) is greater than P1 (44.1 W), the power at P1 is now stored into Pmpp_3 and the power at P2 is stored into Pmpp_1. Then, the algorithm goes to the right of P2 again and tracks the next MPP at P3.After that the power at P2 is stored into

Pmpp_3 and the power at P3 is stored into Pmpp_1 because P3 (56.4 W) is greater P2 (51.4 W). Then, the algorithm stops the searching process because Vmax (43.2V) is reached and Duty_1 is used as the duty cycle of the converter, since, P3 has the largest power among the others and it is at the right most side of the P_V curve. Finally, the power of P_Varray is observed in block_21.

CONCLUSION

In this study, a modified incremental_ Resistance algorithm has been used to identify the Global-MPP for the P_Varray under uneven light conditions and also load variation. To increase the response of maximum-power point identifying system a new algorithm is used in which turn on and turn off period of converter is adjusted. The simulation results shows that the Increment_Resistance method added with some alterations enables to track the LMPPTs as well as Global MPPTs very effectively and accurately with less numbers of steps. In proposed system, losses during Global MPP tracking is minimized under ULCs.

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